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UNITED STATES DEPARTMENT OF AGRICULTURE

Indoor Composting for Mushroom Culture

By Edmund B. Lambert, *pathologist, Division of Mycology and Disease Survey, Bureau of Plant Industry*

CONTENTS

INTRODUCTION

Recent studies on the preparation of mushroom compost have shown that outdoor composting in conventional heaps is relatively inefficient because more than half of the manure in these heaps may be decomposing under anaerobic conditions or at excessively high temperatures, whereas the most rapid conversion of stable manure to a compost suitable for mushroom mycelium takes place under aerobic conditions at moderately high temperatures.[1] In these studies it was also shown that fresh manure can be converted into a compost suitable for mushroom mycelium in less than 2 weeks, if the temperature is maintained between 120° and 140° F., the moisture is properly controlled, and aeration is assured, as contrasted with 4 or 5 weeks in outdoor compost heaps.

In as much as it is the usual commercial practice to maintain approximately these conditions in mushroom beds during "sweating out" following the outdoor composting, it seemed probable for experimental purposes at least that compost suitable for mushroom culture could be obtained by subjecting trays or beds of fresh stable manure to proper conditions. This was confirmed in preliminary experiments made in 1938 in which normal yields of mushrooms were obtained from beds made up of compost prepared from fresh manure fermented entirely by a prolonged sweating out indoors under controlled conditions with no outdoor composting whatever. The experiments were then enlarged so that 6 experimental growing rooms of 48 plots each were devoted to determining the requirements for the conversion of

[1] Lambert, E. B. studies on the preparation of mushroom compost. Jour. Agr. Res. 62: (In press.)

fresh manure to a satisfactory mushroom compost by means of fermentation in beds or trays under controlled conditions indoors.

The results of these experiments indicate clearly that successful crops can be obtained consistently by following a composting procedure that is essentially a prolonged sweating out. Composting indoors in this way has inherent advantages over outdoor compost heaps for experimental yield comparisons that will be explained in detail later. Furthermore, there are prospects of saving of labor and manure in commercial operations from the applications of principles learned from indoor composting.

PREPARATION OF FRESH MANURE

When manure is obtained fresh from the stables, as was the case in these experiments, it is usually too dry and of too open a texture to maintain a proper moisture content in the beds during prolonged indoor composting. This difficulty was overcome by chopping up the fresh manure so that most of the straw was reduced to pieces about 2 inches long. Water was applied generously during the chopping process, and small amounts of superphosphate or gypsum mixed with soil were added.

The manure was chopped with a silage cutter, and water was applied as it left the silage chopper until the water content was about 250 percent of the dry weight. This was about all it could hold without water running out of the bottom of the heap. Various amounts of soil were added partly to make the manure more compact and partly to act as a carrier for the superphosphate or gypsum. In the first experiments 30 percent of soil, by weight, was added; later it was found that 10 percent was equally suitable. The preliminary experiments showed that the high water content necessary in the beginning of the process tended to make a wet soggy condition in the manure during composting in the absence of a flocculating agent, such as superphosphate or gypsum. Satisfactory results were obtained from the addition of either 2 percent of superphosphate or 1 percent of gypsum.

The manure was chopped, wet down, and mixed with the soil superphosphate and gypsum in one operation (fig. 1). It was then immediately taken into the house and placed in the beds. If left in a pile after chopping and wetting, the bottom of the heap rapidly becomes sour. A day or two of souring in a large heap may produce sufficient acid in the manure to make it necessary to prolong the sweating out indoors for 2 or 3 days, and this should be avoided whenever possible. The beds were filled at the rate of 150 pounds for 10 square feet of bed space (fig. 2). Because of the increased weight of the manure due to the added soil and water and the comparatively small loss during indoor composting, the bed space filled from a ton of fresh manure was somewhat in excess of 200 square feet, which is about twice the usual coverage.

TEMPERATURE CONTROL

The desired temperature range for composting in the bed appears to be between 120° and 140° F. Decomposition is not so rapid below

120°, and above 140° there is danger of upsetting the nutritive balance in the manure to favor weed molds. The temperature of the manure inside the beds was controlled by cooling or warming the air surrounding the beds.

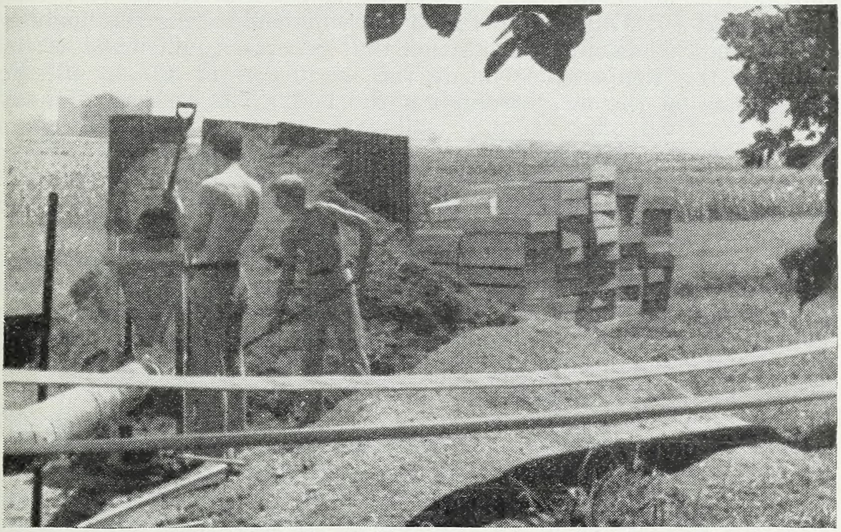

FIGURE 1.—Mixing water, soil, and fertilizers with chopped manure as it is blown from an ensilage cutter.

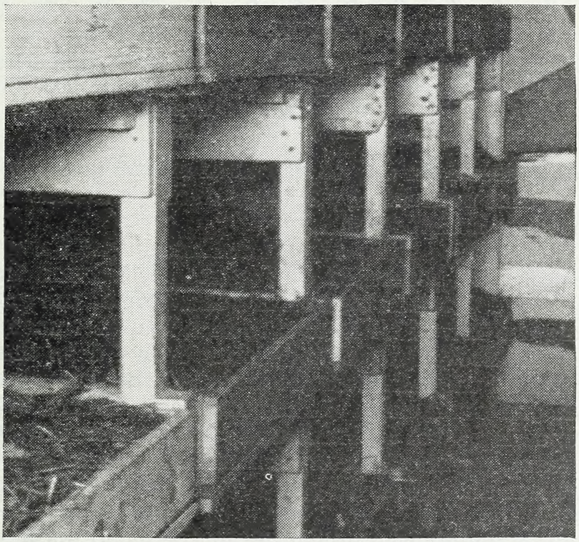

FIGURE 2.—Trays filled at the rate of 13 to 15 pounds per square foot with fresh manure prepared for indoor composting. The sides of these trays are 4 inches high.

The difference between manure temperature (center of bed) and air temperature surrounding the bed appears to be a simple index of the

relative amount of heat generated from day to day as the composting proceeds, and indirectly an index of the amount of easily decomposed carbonaceous material remaining in the compost. Figure 3 shows this difference diagrammatically and also indicates the approximate control of air temperature necessary to maintain a manure temperature of 135° F. During the first 3 days of composting the manure goes through a violent fermentation that generates sufficient heat to maintain the temperature inside the manure from 30° to 40° F. higher than in the air surrounding the bed. The amount of heat

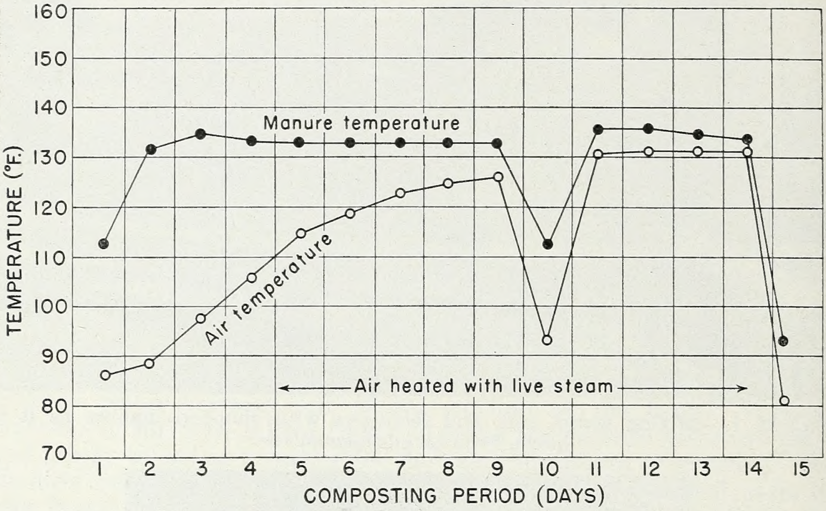

FIGURE 3.—Diagram showing the relation of the temperature of the manure in the beds to the temperature of the air surrounding the beds throughout the composting period. Manure mixed and moistened on the 10th day of composting; beds cooled and spawned on the 15th day.

generated decreases from day to day until after 5 or 6 days it is about equivalent to that produced by manure during a normal sweating out following outdoor composting.

In the experiments at the Arlington Experiment Farm, Arlington, Va., the excess heat generated during the second and third days of composting was controlled by opening the door of the growing room and directing the flow of air from a 16-inch fan, thermostatically controlled, into the doorway. Usually after 3 or 4 days the amount of heat generated by the manure had receded so that some auxiliary heat was needed. In some cases the manure temperature was kept at a proper composting level by raising the air temperature from day to day with steam, thermostatically controlled. In others the manure temperature was allowed to drop slowly, and auxiliary steam heat was delayed until the last 2 or 3 days of composting. Temperature stratification of the air was prevented in the usual manner during the entire composting process by means of fans set vertically in the aisle of the growing room.

As with the customary sweating out process, crop failure will result from improperly controlled temperatures. If the manure temperature is allowed to go above 140° F. for several hours the

chances of a maximum crop are greatly reduced, and if the air temperature in all parts of the house does not at some time reach 130° insect control will not be satisfactory. The use of auxiliary heat during the last 2 or 3 days of the composting is considered by the writer as an essential part of the composting process for reasons that will be explained in the discussion of the control of fungus diseases and insect pests (see p. 7). In the experiments at Arlington Farm, low pressure steam, liberated into the air by means of perforated pipes, has been used as an auxiliary source of heat during sweating out for more than 10 years and there has been no difficulty from steam overwetting the manure, provided it is not liberated directly over a bed and the beds are protected from the dripping of water condensed on the ceiling of the growing room. As stated before, the temperature of the manure in the center of the bed should not be allowed to go above 140° at any time during the composting process. To prevent the steam from carrying the temperature too high a thermostatic control was used, which was arranged so that the bulb actuating the control was suspended in the air near one of the beds. With this arrangement uncontrolled fluctuations in the air temperature were never more than 3°, and there was less than 1° fluctuation in the manure temperature.

This should not be taken to mean that all parts of the bed were uniform in temperature. As a matter of fact the temperature of the manure was always greater in the center of the bed than in the outer layers nearer the cooler air surrounding the beds. During the early part of the composting period this difference might be as much as 10° F., whereas during the last few days, when the fermentation had slowed down, the difference would be less than 5°.

With thermostatic control it is possible to regulate the composting temperature so that most of the manure is within a 10° range, but the optimum 10° or 15° range within the suggested limits of 120° up to 140° F. has not yet been determined.

MOISTURE CONTROL

In all of the experiments there was a tendency for the manure to lose water into the atmosphere. The beds as a whole dried out most rapidly during the first few days when the temperature gradient was greatest between manure inside the bed and the air surrounding the beds. This appears to be due to the tendency for water to move along the decreasing vapor-pressure gradient, which exists between the comparatively warm air within the beds and the cooler air surrounding them even though the air surrounding the beds might have a higher relative humidity than the air inside the compost.

The relatively large moisture content supplied at the time of chopping takes care of most of the loss during fermentation. In the experiments at Arlington Farm, however, it was found desirable to add water to the beds on the third and fifth days and again to mix the manure and water it to a desired moisture content (about 180 to 200 percent) after 8 or 10 days of composting. In order to accomplish the final mixing in comfort the rooms were opened up and cooled off overnight before watering and later brought back with steam to at least 120° F. for a day or two to obtain an even distribution of

moisture in the compost. Very little loss of moisture takes place at this time because of the reduced differential between the manure and air temperatures.

DURATION OF COMPOSTING

The most satisfactory length of the composting period depends on the condition of the manure when it is put into the beds. Manure fresh from the stables undoubtedly should be composted a few days longer than manure that has been a week or two in a freight car en route to the grower. Likewise, manure that has been allowed to become sour by standing under anaerobic conditions will take longer to decompose, and manure that has been excessively wet will take 1 or 2 days longer to reach a proper composted condition than manure that has been properly moistened before composting.

At the end of indoor composting the criteria used to determine the suitability of the compost are much the same as those used by ex-

TABLE 1.—*Effect on yield of mushrooms of differences in duration of composting period and in amount of moisture in the manure at the time of filling*

EXPERIMENTAL DATA

Days composted (number)	Bed No.	Yield when approximate percentage of water to dry matter was— 200: Single plots	200: Mean	250: Single plots	250: Mean	300: Single plots	300: Mean	Sums	Mean
		Ounces [1]	*Pounds* [2]	*Ounces* [1]	*Pounds* [2]	*Ounces* [1]	*Pounds* [2]	*Ounces* [1]	*Pounds* [2]
8	1	258		268		225			
	2	251	1.44	219	1.52	112	0.99	2,540	1.32
	3	207		308		148			
	4	208		182		154			
10	1	276		272		277			
	2	256	1.60	279	1.48	258	1.52	2,950	1.53
	3	216		297		196			
	4	271		106		246			
12	1	293		309		212			
	2	286	1.79	258	1.73	240	1.36	3,134	1.63
	3	305		251		188			
	4	265		295		232			
14	1	256		253		261			
	2	272	1.66	265	1.75	233	1.40	3,010	1.60
	3	281		270		195			
	4	255		259		210			
Sums		4,156		4,091		3,387		11,634	
Mean			1.62		1.62		1.32		

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Sum of squares	Mean square [3]
Between moistures	2	22,734	**11,366
Between lengths of composting	3	16,555	**5,518
Moistures × lengths of composting	6	9,793	1,632
Between beds (blocks)	3	9,723	3,241
Beds × treatments (error)	33	40,062	1,214
Total	47	98,867	

[1] Per 10 square feet.
[2] Per square foot.
[3] **=Probably significant; odds greater than 99 to 1.

perienced growers at the end of the conventional composting procedure. The manure must be friable, dark brown, speckled with gray fire fang, free from an ammonia odor, and the average pH should be less than 8.0. This condition usually will be reached some time between 8 and 14 days. In the experiments at Arlington Farm the manure was chopped and moistened on the same day it was hauled from the stables, and in most cases it was placed in the beds the following day. Under these conditions the most satisfactory length of composting was 12 days. The results of tests conducted to determine the relation of length of composting and moisture content at time of filling to mushroom yield are summarized in table 1. It will be noted that the poorest yields on the average are obtained from the plots that received an excess of water and were composted only 8 days. The plots composted 12 days and 14 days with moderate moisture were uniformly satisfactory.

CONTROL OF FUNGUS DISEASES AND INSECT PESTS

No difficulty was experienced with weed molds, such as the olive green mold or the plaster molds, in plots that were composted a sufficient length of time within a proper temperature range. All cases of weed mold invasion could be traced to deliberate under-composting or overheating. In the experimental rooms at Arlington Farm insects were completely eradicated during the composting period without the usual cyanide or sulfur fumigation by maintaining an air temperature of 130° F. with auxiliary heat and circulating the air with fans during the last 2 or 3 days of composting. It should be noted that the above statement applies particularly to the last 2 or 3 days of composting, because it is only at this time, when the difference between air temperature and the manure temperature is reduced to less than 5° F. (see fig. 3), that it is possible to raise the air temperature to 130° F. without running a risk of overheating the manure.

It is understood, of course, that after the compost cooled and the rooms were opened the usual control measures were observed to prevent the entrance and multiplication of insects and disease fungi.

QUALITY AND YIELD OF MUSHROOMS

The quality of the mushrooms produced from indoor composting was the same as from beds composted in the conventional manner (fig. 4). The experimental beds in the spring of 1940 produced mostly small mushrooms after the first break, but, as this frequently occurs in commercial culture, no special significance was attached to it.

The yield of mushrooms per square foot of bed space averaged between 1½ to 2¼ pounds on beds that were not deliberately given a treatment injurious to the crop. So many factors enter into the production of a good yield of mushrooms that it is difficult to judge the potential worth of a system, such as the one under discussion, from a few yield test figures without seeing the beds in all stages of production. In the writer's opinion the yields per square foot were excellent considering the conditions under which the crops were grown.

When considered from the point of view of yield of mushrooms per ton of manure in the beds the indoor composting system compared very favorably with the old system. In the Arlington Farm experiments the manure was placed in the beds at a rate of slightly more than 200 square feet per ton of fresh manure as received from the stables, whereas

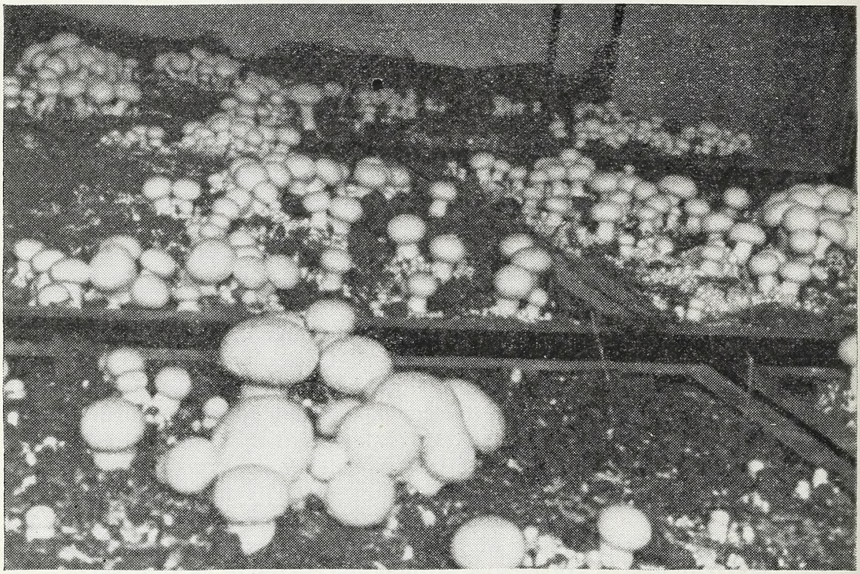

FIGURE 4.—Typical first break on beds prepared by indoor composting.

commercial growers at the present time fill only 70 to 100 square feet with a ton of manure as received from the dealer. In the spring crop the check plots yielded at the rate of 1¾ pounds per square foot.[2] When considered on a basis of raw material the beds yielded at the rate of 300 to 400 pounds of mushrooms for every ton of fresh manure.

INDOOR COMPOSTING AS AN IMPROVED METHOD FOR COMPARING SUPPLEMENTS OR SUBSTITUTES FOR MANURE

In making comparisons of manure supplements and synthetic composts the system of composting under controlled conditions may be used to advantage in small glass jars, in trays, or in sections of a bed. In practice it has been found desirable to run numerous exploratory tests in glass jars to determine the effect of various treatments and combinations of treatments on the suitability of the compost for mushroom mycelium. The materials showing the most promise are then tested further in small plots on the bed. Briefly, the tests in glass jars are made by holding jars of prepared compost between 125° and 130° F. for the required number of days and following this by inoculation with mushroom spawn and incubation at 70° F. If the material in the bottles is reduced to a fine texture; if moisture, temperature, and aeration are properly controlled; and if treatments are

[2] For comparison with commercial yields the figures shown in tables 1, 2, and 3 should be reduced about 20 percent, as they include the stems and stubs.

replicated three or four times, the effect of different treatments is usually susceptible of critical analysis. This method of comparing materials has distinct advantages over pure culture tests in that the results may be directly applicable to the planning of yield comparisons in the beds, whereas the results of pure culture tests are only suggestive when applied to the mixed-culture conditions of mushroom compost.

The advantage of making yield comparisons with materials composted in trays or in small sections of a bed instead of in outdoor compost heaps lies in the fact that the replication of plots in the bed receiving different treatments insures the replication of the entire composting and cultural procedure. With the outdoor heaps comparable results can be obtained only through the replication of whole experimental compost heaps to measure the uncontrolled variability of composting conditions between heaps and by following this with replicate test beds from each heap to sample variability within the heaps. In most cases the cost of doing this would be prohibitive except for a very limited number of tests.

The experiments summarized in tables 1, 2, and 3 illustrate the type of experimental data that may be obtained with the indoor composting method. It will be noted that in each of the experiments 12 treatments have been compared and that each treatment has been replicated 4 times. To obtain comparable data with outdoor heaps at least 48 compost heaps would be necessary to sample variability between heaps, and if variability within the heaps were measured the number of plots on the bed would need to be increased 4 times, or a total of 192 plots.

It is interesting to note that significant effects are indicated in tables 1 and 2, due to length of composting, amount of moisture in the bed, amount of dried blood added, and the interaction of length of composting with the amount of dried blood added. The data in table 3 suggests a greater effect of the sulfate ion than of either potassium or calcium as indicated by the fact that the most significant treatment variance is due to interaction. It was clearly demonstrated by these and similar experiments that length of composting cannot be considered as an independent variable in its effect upon mushroom yields because it is geared to other variables, such as the amount of nitrogenous material in the compost. These influence the rate of conversion of certain materials in the compost to products of decomposition favorable to the mushroom as a source of energy for growth and fruiting in the presence of competing micro-organisms. Interactions of this kind are much more difficult to demonstrate by the outdoor composting system than by experiments employing controlled composting.

TABLE 2.—*Effect on the yield of mushrooms of adding to the compost superphosphate or gypsum and of composting for two different lengths of time with three levels of dried blood*

EXPERIMENTAL DATA

Duration of composting in days (number)	Mineral supplements added	Yield when amount of dried blood added was— None: Single plots	None: Mean	1 percent: Single plots	1 percent: Mean	3 percent: Single plots	3 percent: Mean	Sums	Mean
		Ounces[1]	*Pounds*[2]	*Ounces*[1]	*Pounds*[2]	*Ounces*[1]	*Pounds*[2]	*Ounces*[1]	*Pounds*[2]
10	Superphosphate 1 percent.	242 212 215 250	1.43	109 94 98 112	0.64	20 3 79 65	0.26	1,499	0.78
								(3,171)	(.79)
	Gypsum 1 percent.	244 313 220 187	1.50	133 115 248 78	.89	58 6 14 56	.21	1,672	.83
13	Superphosphate 1 percent.	358 369 235 292	1.98	333 371 378 341	2.21	168 291 268 298	1.60	3,702	1.93
								(7,413)	(1.92)
	Gypsum 1 percent.	348 379 268 290	2.00	419 404 439 305	2.44	85 260 195 319	1.32	3,711	1.92
Sums		4,422		3,977		2,185		10,584	
Mean			1.72		1.54		.84		

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Sum of squares	Mean square[3]
Between amounts of blood	2	175,280	87,640**
Between mineral fertilizers	1	690	690
Amounts of blood × mineral fertilizers	2	7,960	3,980
Between lengths of composting	1	374,886	374,886**
Lengths of composting × amounts of blood	2	59,377	29,689**
Lengths of composting × mineral fertilizers	1	560	560
Lengths of composting × amounts of blood × mineral fertilizers	2	575	287
Between beds (blocks)	3	4,067	1,356
Beds × treatments (error)	33	80,756	2,447
Total	47	704,151	

[1] Per 10 square feet.
[2] Per square foot.
[3] **=Probably significant; odds greater than 99 to 1.

TABLE 3.—*Effect on yield of mushrooms of adding to the compost different amounts and combinations of potassium sulfate and calcium sulfate*

EXPERIMENTAL DATA

Potassium sulfate added (percent)	Bed No.	Yield when amount of calcium sulfate added was—						Sums	Mean
		None		½ percent		1 percent			
		Single plots	Mean	Single plots	Mean	Single plots	Mean		
		Ounces [1]	*Pounds* [2]	*Ounces* [1]	*Pounds* [2]	*Ounces* [1]	*Pounds* [2]	*Ounces* [1]	*Pounds* [2]
0	1	366	2.08	392	2.35	441	2.51	4,453	2.31
	2	337		367		404			
	3	343		368		401			
	4	291		379		364			
⅛	1	374	2.28	353	2.43	371	2.30	4,502	2.34
	2	401		405		414			
	3	341		377		374			
	4	350		424		318			
¼	1	394	2.35	447	2.43	435	2.27	4,516	2.35
	2	409		392		381			
	3	371		350		355			
	4	332		369		281			
½	1	392	2.34	406	2.41	387	2.16	4,430	2.30
	2	367		420		368			
	3	368		350		357			
	4	379		369		271			
Sums		5,811		6,168		5,922		17,901	
Mean			2.26		2.40		2.31		

ANALYSIS OF VARIANCE

Source of variation	Degrees of freedom	Sum of squares	Mean square [3]
Between amounts of potassium sulfate	3	410	137
Between amounts of calcium sulfate	2	4,173	2,086
Potassium sulfate × calcium sulfate	6	11,536	1,923*
Between beds (blocks)	3	24,464	8,155**
Beds × treatments (error)	33	26,042	789
Total	47	66,625	

[1] Per 10 square feet.
[2] Per square foot.
[3] *=Probably significant; odds between 19 to 1 and 99 to 1.
**=Probably significant; odds greater than 99 to 1.

ANALYSIS OF VARIANCE AND DESIGN OF THE EXPERIMENTS

In planning experiments to test the effect of different phases of the indoor composting process on mushroom yield, precautions were taken to reduce the uncontrolled variability and facilitate an analysis of variance. Uniformity trials have shown that bed levels may sometimes be an important source of variability.[3] In view of this all treatments were randomized on each bed level. In effect then each of the four bed levels was handled as a randomized block. Variability within the blocks was reduced by thoroughly mixing the compost in each block before applying the treatments under consideration.

The large mean square for block differences in table 3 illustrates the gain in precision sometimes obtained as a result of mixing the compost and arranging the experiment so that blocks correspond to bed levels.

[3] LAMBERT, E. B. SIZE AND ARRANGEMENT OF PLOTS FOR YIELD TESTS WITH CULTIVATED MUSHROOMS. Jour. Agr. Res. 48: 971–980, illus. 1934.

The coefficient of variability of a single plot averages between 10 and 15. When it is remembered that mushrooms are picked from each plot for a 3-month period this amount of variability cannot be considered excessively high. Less variability would be distinctly desirable, but this figure compares favorably with that from plots of similar size representing variability within single outdoor compost heaps of either stable manure or synthetic compost.[4] As the yield from each plot with the indoor system was the end product of an entire composting process, the variability between replicates of these plots is more strictly analogous to the variability in the yield of plots representing differences both within and between replicate outdoor compost heaps. In the writer's experience the variance between heaps usually has been considerably higher than that within the heaps.

Brief analyses of variance and the arrangement of treatment combinations are given in tables 1, 2, and 3. These data will serve to illustrate the degree of precision that can be expected in making comparative yield tests with the indoor-composting system. The experiments were laid out in factorial design. It is evident from these tables that yield differences may be tested by the indoor composting method with sufficient precision to enable a critical analysis of treatment effects.

SUGGESTIONS FOR COMMERCIAL GROWERS

The manure received by commercial growers is usually somewhat more decomposed and easier to wet than the manure used in the Arlington Farm experiments, which came fresh from the cavalry stables at Fort Myer, Va. Because of this the commercial growers who have tried indoor composting have experienced less difficulty with breaking up and moistening the manure and with temperature and moisture control in the bed than would have been encountered with manure fresh from stables.

Whether shortening outdoor composting and prolonging indoor composting will be found feasible by commercial growers depends in the last analysis on whether a saving of labor and manure can be made sufficient to warrant the change in procedure. It is possible that many growers will find the method presents more difficulties than advantages. On the other hand, growers who already have turning machines to break up the manure will want to give controlled composting serious consideration. For growers interested in filling an experimental house, the following procedure is suggested:

1. Wet the manure while forking it from the car and at every opportunity until sufficient water has been applied, usually somewhat more than would be desirable for composted manure at filling time.
2. Add to each ton of manure, either on the cars or when piled up in the composting yard, a mixture of 20 pounds of superphosphate and 20 pounds of gypsum, using about 150 pounds of soil as a carrier to facilitate the distribution of the fertilizers.
3. Break up the manure with from 1 to 3 turnings in a manure-turning machine. The number of turnings necessary will depend on the efficiency of the machine in breaking up the manure and the facilities for wetting the manure sufficiently and uniformly. If the manure is received fresh from the stables the process of breaking it up and wetting it should be prolonged over a period of 2 or 3 days in

[4] See footnote 3 and SINDEN, J. W. SYNTHETIC COMPOST FOR MUSHROOM CULTURE. Pa. Agr. Expt. Sta. Bul. 365, illus. 1938.

order to soften the straw sufficiently to enable it to take up water readily and to allow the manure to go through its initial violent fermentation. On the other hand, if the manure has been several days on a freight car, the turnings can be made with little or no time interval, as the object is to break up the manure and moisten it rather than to compost it.

4. Do not allow the pile to remain on the wharf long enough to heat above 145° F. or to turn sour after it has been broken up and wet. In case a short preliminary fermentation appears to be desirable, it will be found that both excessively high temperature and anaerobic fermentation can be largely avoided by low piles (2 to 3 feet high) and turning at daily or 2-day intervals. Carry the manure into the house immediately after the final turning. Fill at the rate of about 150 to 200 square feet of bed space per ton of wet manure.

5. After the manure begins to warm up be sure to leave the doors and ventilators open enough to prevent overheating during the first days of sweating out. If necessary fans should be directed into the doorway to prevent overheating. The amount of heat produced during the first 2 days is surprisingly great. To maintain a temperature of between 120° and 135° F. in the center of the beds the air temperature should be regulated approximately as follows: First day after filling 90° or below, second day 95°, third day 98°, fourth day 105°, fifth day 110°, sixth day 115°, seventh day 120°, eighth, ninth, tenth days 125° to 130°. The difference between the air temperatures and manure temperature will vary somewhat with different sources of manure. It should be clearly understood that the foregoing schedule of air temperatures is based on estimated differences between the air temperature and manure temperature, and that the schedule should be modified to keep the manure temperature between 120° and 140°. No harm will come from several days at 120° or somewhat below, but the manure should under no circumstances be allowed to go above 145°, preferably not over 140°. If this happens early in the composting the harmful effects of overheating can be partly overcome by prolonging the composting 3 or 4 days over the normal period, but the chances of obtaining a full crop will be greatly reduced.

6. In most of the experiments at Arlington Farm supplementary heat was applied in the form of low pressure steam as soon as the temperature began to drop below 125° F., and fans were run during the entire composting period to reduce the difference in temperature between the top beds and the bottom beds. In commercial practice it may be advisable to save electricity and steam by delaying the use of steam and the continual running of fans until the last few days of the composting period. Most houses may be brought through a fairly satisfactory "heat" during the first week with only an occasional running of the fans and no auxiliary heat by allowing the top beds to come through peak heat 2 or 3 days ahead of the bottom beds. A comparatively low fermentation temperature—120° to 125°—is advisable during the first few days of composting to lessen the danger of overheating and excessive loss of water while the manure is going through its most violent fermentation. During the last 3 or 4 days of composting it would seem advisable to reduce the temperature differences from the top to the bottom of the house with fans and to raise the temperature of the beds to between 130° and 135°. This

assures a good growth of fire fang due principally to *Actinomyces* spp., which tend to discourage the growth of weed molds and will usually bring the air temperature up to 130°, which is sufficient to eradicate insect pests.

7. Moisture is controlled by watering the beds during the composting. More water is lost during the first 4 days than during the remainder of the sweating out, and it is necessary to keep the center of the beds quite moist during this period. In the experiments at Arlington Farm the beds were broken up and remoistened after 7 or 8 days to get an even distribution of water in the manure. This should not be necessary in commercial practice because the manure will be either partly composted en route to the grower or put through a short fermentation on the wharf while it is being moistened and broken up.

8. The appearance of the manure pH value and lack of an ammonia odor should be used to determine when the composting is complete. This will probably be between 10 and 12 days, depending on the condition of the manure when placed in the beds.

9. Growers will be surer to eradicate insects if sufficient auxiliary heat in the form of steam is liberated into the air of the house during the last 2 days of composting to raise the air temperature to 130° F. At this time the difference between the air temperature and manure temperature will have receded to about 5°, so that there will be little danger of driving the manure temperature above 140°. No fumigation will be necessary if the air temperature in all parts of the house and the floor temperatures reach 130° for several hours. Otherwise, the usual cyanide fumigation at peak heat is recommended.

10. After composting the usual procedure is followed for spawning, casing, disease and insect control, and other cultural practices.

SUMMARY AND CONCLUSIONS

Studies are described leading up to a method of fermenting organic composts indoors under controlled conditions that makes the preparation of mushroom compost more nearly a controlled industrial process. In shallow layers of compost, such as standard mushroom beds, fermentation conditions of temperature, moisture, and aeration were controlled close enough to the optimum to produce a satisfactory mushroom compost in less than 2 weeks.

For experimental comparisons of the effect on the production of mushrooms of different substitutes and supplements for stable manure the indoor composting method has the inherent advantage of permitting the experimenter to conduct preliminary tests cheaply in small glass containers and later, in making yield tests, to replicate composting conditions in trays or test plots without the cumbersome and expensive replication of outdoor compost heaps.

There are several principles learned from the studies on indoor composting that are of interest to commercial growers:

The sweating out process following the usual outdoor composting should be considered as an integral and important part of the composting process and not merely as a means of eradicating harmful fungi and insects.

Outdoor composting may be considerably shortened or eliminated altogether, provided sweating out is prolonged approximately 1 day for every 3 days omitted from the outdoor composting.

Manure takes on characteristics typical of each new composting environment to which it is subjected, and, therefore, the last few days of sweating out are usually the most important.

It is only during the last 3 or 4 days of indoor composting that the air temperature surrounding the beds can be raised to 130° F. without danger of overheating the manure or excessive drying out. Usually the heat generated by the manure will not be sufficient at this time to bring the air temperature to 130°. Therefore the application of auxiliary heat during the last few days is highly desirable from the standpoint of final conditioning of the manure and insect eradication.

When outdoor composting is reduced to 2 or 3 turnings at rapid intervals the process may be considered merely as a means of mixing and moistening the manure while carrying it through the initial explosive fermentation to reduce the tendency to overheat and lose moisture during the subsequent prolonged sweating out.

The extent to which it will be found advisable in commercial practice to shorten outdoor composting and lengthen indoor composting will vary from one establishment to another, depending on the facilities available for mixing and breaking up the manure and for controlling temperature and moisture during sweating out. With proper facilities there appear to be good prospects of a saving in both labor and manure from shortening the outdoor composting. In the experiments at Arlington Farm indoor composting was found to require less labor than composting in outdoor heaps, and normal yields were obtained on beds using about half the usual amount of fresh manure per unit of bed space.

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